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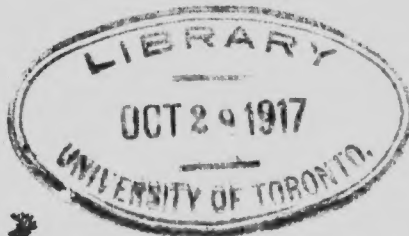
ATERITIC ORE DEPOSITS

With Comments on the Nature
of Laterites in General

By
WILLET G. MILLER

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Reprinted from Vol. XXVI, Part I,
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With Comments on the Nature of Laterites in General

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Although ore deposits of lateritic origin do not occur in Canada they are, at least, of economic interest here. The nickel ores of New Caledonia, which has been the only serious competitor with Sudbury, and the nickeliferous iron ores of Cuba, the production of which may have some effect on the output of the iron ores of the Lake Superior region, are of the nature of laterite.

While the name laterite was introduced over a century ago, 1807, for certain superficial deposits, red "earth," of India, from which bricks (*later*, a brick) were made, it is only within the last two decades that careful study has begun to be undertaken of the materials to which the name has been more or less loosely applied. During the last ten years, a number of papers dealing with laterites have been published in the Geological Magazine, and the Geological Survey of India has given much attention to the subject. It would appear, however, that much systematic work remains to be done.

L. L. Fermor says: Few natural mineral products have aroused more general interest or been more provocative of discussion amongst geologists than that superficial rock-formation so typical of the tropics known as laterite. This material excites interest not only because of its chemical composition, but also on account of its wide distribution. It has been recorded, for instance, from tropical South America (e.g., the Guianas and Brazil), Central Africa (e.g., Guinea and East Africa), the Seychelles, India, the Malay Peninsula, the East Indies and Western Australia. Many papers have been published dealing with its distribution, composition, and also its origin, to explain which many hypotheses have been invented.¹

From following quotations concerning the character of laterite, it will be seen that only two kinds of superficial weathering of silicate rocks have been recognized, by writers on the subject, viz., (1) that which gives rise to so-called laterite, silica and certain other constituents being practically all carried off in solution, and (2) weathering in temperate climates which gives rise to clay, in which the silica remains combined with alumina and water. The author desires to point out, however, that there are at least two other kinds of weathering, viz., (3) that represented by the nickel ores of New Caledonia, which contain a comparatively high percentage of silica combined with magnesium and other elements, and (4) the bauxite deposits of Arkansas, higher in silica in certain of their upper layers than in the bauxite below. Tables of analyses of both the New Caledonia nickel ores and the bauxites of Arkansas are given on following pages. From a consideration of them it would appear that the present, accepted definition of the term laterite should be modified, or that the term should be employed only in its former general or stratigraphic sense.

A brief description of the lateritic deposits of the several metals, that occur in important quantities in such deposits, is given on following pages.

* A paper presented before the Royal Society of Canada, Section IV, May, 1917.

¹ Geol. Mag., Vol. VIII, 1911, p. 454.

Although the Cuban deposits have been studied only within the last ten years, a much more systematic chemical examination has been made of them than of laterites in any other part of the world. Indeed, practically the only published analyses of laterites at various depths in the deposits are those of Cuba. Writers on other deposits have been content, in most cases, to give analyses representing merely the upper parts of the weathered material, thus ignoring the fact that there is no sharp line of division between the more highly oxidized and leached capping and the underlying material. As shown in a following table of analyses, a high percentage of alumina, for example, is characteristic of only a foot or two of the uppermost part of some deposits, while in other cases it extends downward much farther. The most detailed analyses available, those of Cuban deposits, 35 or 40 feet in thickness, that have been made of samples, representing each foot in thickness, show clearly that the change in chemical composition is gradual. The name laterite should, therefore, not be applied merely to the red-colored surface layers of the deposits. In Cuba the iron-ore deposits at Mayari are mined by steam-shovel methods to an average depth of about 19 feet. The upper layer, 5 or 6 feet in thickness, is of a crimson-brown hue; the middle layer, of greater thickness, is yellowish-brown, and the lower layer, also 5 or 6 feet thick, is of a lighter shade of yellowish-brown. The difference in colour of the layers is due chiefly to the state of oxidation of the iron, but is also influenced by the percentage of alumina.¹

As a member of the Royal Ontario Nickel Commission, the author visited both Cuba and New Caledonia during the year 1913. The deposits of these two widely separated islands are the most important from the economic point of view of any of those yet exploited. It may be added that the cobalt deposits of New Caledonia, also of lateritic origin, controlled the world's markets for the ore of this metal, prior to 1903 when those of Cobalt, Ontario, were discovered.

In addition to those of iron, nickel and cobalt, other ores of lateritic origin that have been worked include certain manganese, aluminum (bauxite) and gold deposits. Lateritic ores emphasize the importance of the igneous rocks, especially, as a source of metals.

In discussions which have taken place as to the character of laterite, it has been generally agreed that the term should be applied to subaerial decomposition products that contain a low percentage of combined silica, existing as hydrated aluminum silicate, as contrasted with clays of similar origin. Fermor would limit the combined silica to 5 per cent. in pure laterite. It will be seen from following analyses of the Cuban materials, from the surface to a depth of twenty feet or more, table No. 4, that they fall within Fermor's classification of laterites. On the other hand, the New Caledonia nickel ores contain from 35 to 50 per cent. of silica, table No. 2, not in the form of clay but with much hydrated nickel magnesium silicate. The question then arises as to whether or not these New Caledonia materials should be classed as laterites as defined by Fermor and other writers. While they contain iron and aluminum in the form of what have been called true laterites, they differ from them in the content

¹ A list of publications on the Cuban deposits is given in J. F. Kemp's instructive paper, *The Mayari Iron-Ore Deposits of Cuba*, A.I.M.E., Vol. LI, 1915.

of combined silica and in the comparatively high percentage of magnesia. These nickel ores do not seem to have been considered by the various writers who have discussed the question "What is laterite?"

Laterite and Clay

Fermor defines laterite, and distinguishes it from clay, in the following words:—

One should not decide whether a given rock is laterite on the basis of the presence or absence of alumina in quantity, but on the presence or absence of any considerable proportion of combined silica. Combined silica means the presence of kaolin or lithomarge, and the larger the amount of such material the closer does the rock approach a clay in composition. Now clays^a are to be regarded as the end products resulting from one mode of superficial decomposition of rocks, and laterites as the end products of another totally distinct mode of decomposition. When a rock breaks down into a *clay* hydrated aluminum silicate is to be regarded as the pure end product, all oxides being removed in solution. When a rock is converted into *laterite*, on the other hand, the reverse holds; aluminum and other silicates are decomposed, and the silicate is removed in solution, presumably in the colloidal form, whilst the oxides of iron, aluminum, titanium, and manganese, which were relatively soluble under the clay-forming conditions, are relatively insoluble under laterite-forming conditions. The oxides of calcium, magnesium, sodium, and potassium are apparently soluble under both sets of conditions. I do not propose to advance here any reasons to account for these two diverse modes of surface alteration of rocks, nor to say anything about the conditions, whether climatic or organic, that bring them about, but to deal only with the results of such changes. *Pure clay*, then, is hydrated aluminum silicate, whilst *pure laterite* is a mixture of one or more, or all, of the oxides of iron, aluminum, titanium, and manganese, more or less hydrated, which I refer to in this paper as the lateritic constituents. Manganese oxide is a somewhat exceptional constituent, and when present usually segregates into masses of comparatively rich manganese-ore, as a rule either psilomelane or pyrolusite.¹

C. M. Weld in describing the Cuban deposits gives a definition of laterite similar to that of Fermor, as follows: "The ore is, in fact, a laterite, a product due to the peculiar form of decomposition known as laterization, which is common to humid tropical climates. The essential characteristic of laterization is the breaking-up of the silicates, with the ultimate almost complete removal of the silica, wherein it differs radically from the kaolinization-processes of the temperate zones."²

In order to show the difference in the products of weathering of rocks of similar character in tropical and temperate climates, respectively, Hugh Warth published some interesting analyses of dolerites of India and Great Britain and of their weathered products.³ The following table shows the results of analyses, the comments on the table being taken from Warth's paper:—

Column i of the table represents the composition of the original Rowley Regis rock, which was obtained as the average of three analyses, two of them by J. H. Waller and a third analysis by Henry.

Column ii, the weathered product of Rowley Regis (steam dry).

Column iii, composition of Dolerite from Poonah on the Western Ghâts in the Bombay Presidency (analysed by my son F. J. Warth, M.Sc.).

Column iv, the composition of the Laterite which rests on the dolerite at Mahabaleshwar, which is also situated on the Western Ghâts (see p. 155, Dec. iv, Vol. X, of this Magazine, April, 1903, by H. & F. J. Warth).

^a I.e., clays formed in situ as distinguished from those deposited as aqueous sediments.

¹ Geol. Mag., Vol. VIII, 1911, pp. 459, 460.

² A.I.M.E., Vol. XL, p. 305.

³ Geol. Mag., 1905, p. 21.

	ROWLEY REGIS		WESTERN GHÂTS	
	I	II	III	IV
SiO ₂	49.3	47.0	50.4	.7
TiO ₂	.4	1.8	.9	.4
P ₂ O ₅	.2	.7	....	....
Al ₂ O ₃	17.4	18.5	22.2	50.5
Fe ₂ O ₃	2.7	14.6	9.0	23.4
FeO	8.3	....	3.6	....
MgO	4.7	5.2	1.5	....
CaO	8.7	1.5	8.4	....
K ₂ O	1.8	2.5	1.8	....
Na ₂ O	4.0	.3	.9	....
H ₂ O	2.9	7.2	.9	25.0
Total	100.4	99.3	100.5	100.0

This table shows the striking difference between the weathering of the Rowley Regis Dolerite and that of the Dolerite of Poonah, which so far may represent the whole of the Deccan Trap. Whilst the Rowley Regis Dolerite yields a product (column ii) which differs comparatively little from the original rock, this Dolerite of the Western Ghâts is altogether changed into a mixture of aluminum hydrate and ferric oxide, the most remarkable fact being the nearly perfect removal of the silica in the latter case. . . .

No chemical reaction is known which can account for such a complete removal of silica as has occurred in India, neither is there any explanation why such a reaction should work in India and not in England. The only hypothesis we have is the one based on Mr. T. H. Holland's novel and ingenious suggestion that the silica might be rendered soluble by lowly organisms which can thrive in the uniformly warm climate of the tropics, and not in a region of lower and varying temperature. However, there is as yet no actual proof for this hypothesis, and under the circumstances it may not be inappropriate once again to draw the attention of chemists to this remarkable phenomenon in case there might after all be a strictly chemical solution of the problem.

The weathered product from India may be classed as bauxite. In the Rowley Regis rock there is no tendency towards the formation of bauxite. The weathered material on the surface of the dolerite in the latter locality has a thickness of about twenty feet.

That very few chemical examinations of laterites have been made till recent years is shown by the following quotation from T. H. Holland's paper published in 1903.¹ Laterites had been frequently described as ferruginous clays. Holland says: "Dr. Warth's suggestion naturally occurred to me, and steps were taken to investigate the chemical constitution of laterite; but before any real progress in the work had been made, Dr. Bauer's paper appeared, and, as I think, practically settled the question. What is true of the Seychelle laterite must, so far as one can judge, be true also of the laterites in India which have not been sifted by running water."

Regarding the origin of laterites Holland says:²

Now, putting these facts together, I would suggest that we look for the explanation of laterite, not in simple chemical reactions, but in the action of some lowly organism having the power of separating the alumina, which, after the manner of many plants, it does not want, from the silica, which is necessary for its life, but which, being in a soluble form, is removed again by the alkaline solutions. Such a form of life might thrive in the moist climate of the tropics, even to a temperate altitude, but might find life intolerable in a land subject to severe winters, such as we get in the temperate zone and in North India, where

¹ Geol. Mag., 1903, p. 60.

² *Ibid.*, p. 63.

we find no laterite. Such an organism would form *kunkar* as well as laterite in a moist, warm climate, the difference in the products being due merely to their after-treatment by water. For obvious reasons, too, such an organism could not live under conditions of kaolinization. But apart from the agency of life I see no chemical reason why an aluminous silicate should undergo a more complete decomposition at the comparatively low temperature of the tropics than at the high temperature of subterranean situations; the contrary, indeed, seems more natural. And if the temperature *does* so affect chemical action we still might wonder why laterite does not occur on the foot-hills of the Himalayas, where there is an abundance of moisture and where the average annual temperature is as high as on the Nilgiris. Chemical changes which cease at low temperatures commence again as soon as the suitable physical conditions are restored, and laterite, consequently, would be expected to form in North India during the summer. But the distribution of an organism might very well be limited by the extremes of climate, when possibly the average annual temperature is not below what would be congenial to it if maintained.

If this fancy turns out to be well founded we must add laterization to the long list of tropical diseases, against which even the very rocks are not safe. But it is a big step between the establishment of a reasonable suspicion and the actual detection of the bacillus at work. There may be many forms of life taking advantage of the soft, moist, lateritic medium, but it will not be an easy matter to convict, amongst these, such as may take an active part in breaking up the aluminous silicates.

It is hard to believe that the few degrees by which a tropical exceeds a temperate climate is sufficient to so strikingly increase the chemical activity of the weak organic acids percolating through the soil. But that such a small difference of temperature affects low forms of life is painfully evident to those who have to maintain the daily fight of life in the tropics.

Laterization Conditions in Cuba and New Caledonia

While certain features of Cuba are similar to those of New Caledonia, both being islands and the one lying about the same distance north of the equator that the other does to the south, the temperature and rainfall, factors in laterization, are somewhat different. The mean temperature of Cuba is given as 76.8° , the lowest average occurring in January when it is 70.3° and the highest in July, when it is 82.1° ; the average rainfall for the past twenty-five years has been 53.57 inches.¹ This average temperature has apparently been determined without taking into consideration that of the greater altitudes. The mean minimum temperature of New Caledonia is said to be 63° and the mean maximum 83° ; between 1908 and 1912 the average rainfall was 72.6 inches, but varies greatly in different years, in 1910 being 96 inches while in 1911 it was 49.7.² There is, of course, no means of determining what changes have taken place in the climates of the two islands during the vast period in which laterization has been in progress.

While the process of laterization is still in progress on both islands, the greater part of the deposits was formed long ago. A. C. Spencer says: "The residual ores of Cuba were formed in Tertiary time, in large part, and perhaps entirely, prior to the deposition of the Lafayette (Pliocene) formation of the Atlantic Coastal plain."³ The basic rocks from which the serpentine of New Caledonia has been derived are considered to be of post-Cretaceous age.

Regarding the mode of formation of the Cuban ores, C. M. Weld has said: "At the same time there is no reason to suppose that laterization processes have ceased; it is in fact probable that new ores are forming to-day wherever opportunity offers. Such opportunity may be considered as at a minimum on the plateaus,

¹ Official Handbook, "Cuba Before the World," Panama-Pacific International Exposition, 1915, p. 22.

² Report Roy. Ont. Ni. Com., p. 246.

³ Occurrence, Origin and Character of the Surficial Iron-Ores of Camaguey and Oriente Provinces, Cuba, A.I.M.E., Vol. XLII, p. 106.

where heavy mantles of material lying nearly horizontally effectively protect the underlying rock from the action of the surface waters.” The occurrence of the Cuban ores, for the most part, on plateaus presents a difference from that of the nickel ores of New Caledonia which are found on hillsides. Many of the serpentine areas of the latter island are broken and dissected, and the plateau structure is not prominent. Hence there has been more working over of the laterite in this island than in Cuba, and there has been more opportunity for the concentration of the nickel contents, the metal being first leached out by water and then deposited at lower levels on the hillsides. Fissures in the rocks also assist in concentration of the nickel.

In general appearance the deposits of Cuba and New Caledonia present a striking likeness, only chemical analysis brings out the fact that certain of the deposits of the latter island are much richer in nickel than any of those discovered in Cuba, and that they contain a high percentage of combined silica and of magnesia.

Composition of Laterites

Table No. 1 shows the composition of laterites from several countries. It has been compiled from various publications.² The analyses of the New Caledonia samples were kindly made for the author by A. L. Clark of Toronto. In certain cases magnesia and other constituents while present have not been determined. Much more complete analyses of the New Caledonia nickel ores are given in table No. 2. This table is of special interest, owing to the content of silica and magnesia of the ores. The composition of the New Caledonia cobalt ores is given in table No. 3, that of the Cuban iron ores in table No. 4, manganese ores of India in No. 5, and bauxite or aluminum ores of Arkansas in No. 6.

¹ The Residual Iron-Ores of Cuba, A.I.M.E., Vol. XL, p. 310.

² Analyses of Cuban samples are taken from publications by Kemp and by Leith and Mead, to which reference is made in this paper; the analysis, India (1), is quoted on a preceding page; that of India (2) is quoted by Clarke, data of Geo. Chem., 3rd Ed., p. 495; that of F. Guinea is from A. Lacroix; those of Borneo and the Philippine Ids. are from Roy, Ont. Ni. Com. Report, pp. 266 and 278.

TABLE No. 1

Analyses of Laterites at Various Depths from Surface

(Note Content of Silica and Magnesia in New Caledonia Ores, Table No. 2.)

	Depth Feet	SiO ₂	TiO ₂	MgO	H ₂ O	Cr ₂ O ₃	Al ₂ O ₃	Fe	Ni+Co
<i>1st Layer.</i>									
Kataviti, N. Caledonia	0-1½	4.2	.....	0.25	11.20	2.10	5.8	51.1	1.95
Dumbéa, N. Caledonia	0-4	5.8	.....	0.30	.....	.....	6.1	50.0	1.69
Mayari, Cuba, 1	0-4	2.49	.....	.....	9.87	1.42	17.04	46.4	0.37
Mayari, Cuba, 2	.....	2.26	.....	.....	11.15	1.89	14.9	48.65	0.59
India, 1	.....	0.70	0.40	.....	25.00	.....	50.5	16.38	.....
India, 2	.....	0.90	1.59	0.20	14.39	.....	26.27	56.01	.....
F. Guinea	.....	2.80	.....	.....	11.40	trace	8.7	54.04	.....
Borneo	0-6	2.75	.....	.....	.....	3.36	.....	53.09	0.39
Philippine Ids.	surface	1.04	.....	.....	6.60	1.15	10.56	54.29	.....
<i>2nd Layer.</i>									
Kataviti	1½-3	26.4	.....	15.60	12.60	1.30	2.4	18.3	6.66
Dumbéa	4-8	8.2	.....	1.70	11.20	.....	4.0	47.5	1.47
Mayari, 1	4-8	2.33	.....	.....	11.00	2.66	7.97	50.32	0.92
Mayari, 2	.....	2.70	.....	.....	12.90	3.17	7.13	51.32	1.20
Borneo	6-9	2.35	.....	.....	.....	3.22	.....	50.01	0.41
<i>3rd Layer.</i>									
Kataviti	3-4½	32.2	trace	.....	.....	0.55	1.5	11.7	7.49
Dumbéa	8-12	23.6	trace	4.8	8.70	1.50	2.8	35.5	2.05
Mayari, 1	8-12	2.72	.....	.....	12.31	3.11	6.88	50.04	1.25
Mayari, 2	.....	7.54	.....	1.5	12.75	3.66	4.97	46.52	2.10
Borneo	9-15	2.30	.....	.....	.....	2.99	.....	51.69	0.45
<i>4th Layer.</i>									
Dumbéa	12-16	45.0	.....	15.80	6.70	.....	0.9	16.8	2.49
Mayari, 1	12-16	2.6	.....	.....	12.85	2.75	6.52	47.18	1.36
<i>5th Layer.</i>									
Dumbéa	16-20	42.8	.....	.....	.....	.....	4.8	16.3	3.64
Mayari, 1	16-20	4.17	.....	.....	12.25	3.33	6.74	47.72	1.36
<i>6th Layer.</i>									
Mayari, 1	20-24	10.71	.....	.....	12.74	3.08	5.80	43.79	1.58
<i>7th Layer.</i>									
Mayari, 1	24-29	35.99	.....	21.56	14.57	2.12	4.11	29.50	1.74

Nickel Ores

New Caledonia has been a producer of nickel ores of lateritic origin since 1875¹. Similar ores in another French island, Madagascar, have attracted attention during recent years but little mining has been done there². Garnierite ores, like those of the two countries just mentioned, have also been shipped from Greece.³

New Caledonia, between latitude 20° 5' and 22° 16' S. and between longitude 164° and 167° 50' E., has a length of about 250 miles and an average breadth of less than 30 miles, the maximum being about 40. Serpentine, derived from peridotites and other basic rocks, occupies about one-third of the surface of the island. Resting in situ over much of the surface of the serpentine are loose products of weathering of varying thicknesses, at least the upper parts of

¹ Report Roy. Ont. Ni. Com., pp. 234-264.² Ibid., pp. 276, 277.³ Ibid., pp. 272-275.

Map of New Caledonia.

which, as shown from the analyses in a preceding table, would be called laterite. But, taken as a whole, these products of weathering, as the analyses show, differ greatly, especially in their content of combined silica, from those that have been described as true laterites from other countries. They also differ from clays in that the silica does not exist in combination with the alumina but with magnesium, nickel, and other elements, the hydrated nickel-magnesium silicate, garnierite, being the most important economic constituent.

The following table, No. 2, of analyses of ores, that are shipped from various localities in the island, shows a striking difference, in the high percentages of silica and magnesia, and the comparatively low percentages of alumina and iron, from the lateritic iron ores of Cuba, for instance. Other analyses are given in table No. 1.



Mining Lateritic Nickel Ore, New Caledonia.

In mining, the upper layer of the deposits, high in iron and low in magnesia and silica, is stripped off. This layer, as shown in the case of the Kataviti mine, in analyses given in table No. 1, is sometimes only a foot or two in thickness, but sometimes much greater. Then the ore, richer in nickel, lying below, is excavated down to a point where the rock becomes hard and compact. The decomposed rim, of a thickness of two or three inches or more, that coats the surface of boulders, that lie near the bottom of the loose material, is scraped off and added to the ore pile. The ore is piled in small heaps, carefully sampled, and the lower-grade ore mixed with the higher so as to form a product containing, as the table shows, an average of about six per cent. of nickel. The lateritic iron ore is not used, although it occurs in quantity on the island in deposits parts of which are workable as sources of nickel and elsewhere.

Production of nickel ore began in Sudbury in 1887, but the competition with New Caledonia was so keen that it was not until 1905 that Sudbury definitely outdistanced its rival. With the exception of Sudbury, New Caledonia has no

TABLE No. 2+
Selected Analyses of Types of New Caledonia Nickel Ores

Name of Mine.	Situation.	Per cent H ₂ O dried at 100°C.	Ni	Co	Fe	Al ₂ O ₃	CaO	MgO	SiO ₂	Loss on ignition.	Cr ₂ O ₃
Fathna	Poro, East Coast.	?	6.51—(Ni & Co)		9.32	1.20	traces	16.36	49.60	?	?
Houailou	"	?	4.84		10.63	0.52	"	22.16	45.64	10.78	1.40
Circé	Between Thio and Nakéty.	?	6.97		10.20	1.27	"	17.40	50.62	?	?
Elise	Thio	26.61	6.80		11.92	1.30	"	19.30	48.52	?	1.20
Prises Alma & Rivoa	Port Bouquet E. Coast.	22.86	6.46	0.13	12.81	0.20	"	24.95	36.82	?	1.20
"	"	23.79	6.77	0.10	12.21	0.62	"	26.30	34.72	?	1.20
Puy-de-Donne & Lucie S.	"	?	6.47—(Ni & Co)		16.79	16.79	?	27.89	35.78	12.09	*
Etoile du Nord	Ma Kaala, W. Coast.	22.53	6.82—(Ni & Co)		12.51	0.63	"	22.39	38.74	"	*
Nouvelle-Espérance	Massif Huazangou W. Coast.	26.30	6.78—(Ni & Co)		12.27	1.42	"	23.19	39.76	"	*
Mines de Voh	Massifs Katérahie & Koniambo	22.60	6.67	0.13	13.83	0.77	"	21.11	42.10	"	1.24
Kataviti	West Coast.	23.91	6.19	0.10	9.10	0.73	"	24.18	41.20	"	*
"	"	24.00	5.71	0.12	9.95	0.77	"	23.91	45.88	"	*
Annie	Massif du Kongouhaou	?	7.74—(Ni & Co)		12.18	0.73	"	18.02	47.79	"	*
Souza	Region Dumbéa.	?	5.45	?	12.65	1.42	"	23.26	38.56	"	*
Monnaie	"	?	4.68	?	9.44	1.07	"	20.43	46.69	9.08	0.60
Gracieuse	"	27.50	7.26	0.15	11.10	1.10	"	18.90	49.98	9.30	0.57
Le Pic	"	26.04	6.35	0.11	12.59	0.41	"	27.03	36.90	8.95	1.38
Barbouilleurs	"	?	6.67—(Ni & Co)		13.58	1.24	0.08	24.21	37.75	10.30	0.60
Tip Top	"	?	4.75—(Ni & Co)		12.38	1.17	"	15.40	48.60	"	*
"	"	?	4.75—(Ni & Co)		11.15	1.28	"	29.43	35.11	10.23	1.47
Tamanou	Ué Bay, S. of I-land.	?	5.93—(Ni & Co)		11.55	0.59	"	27.38	34.73	14.10	"
"	"	?	5.93—(Ni & Co)		11.55	0.59	"	28.51	34.59	16.02	"

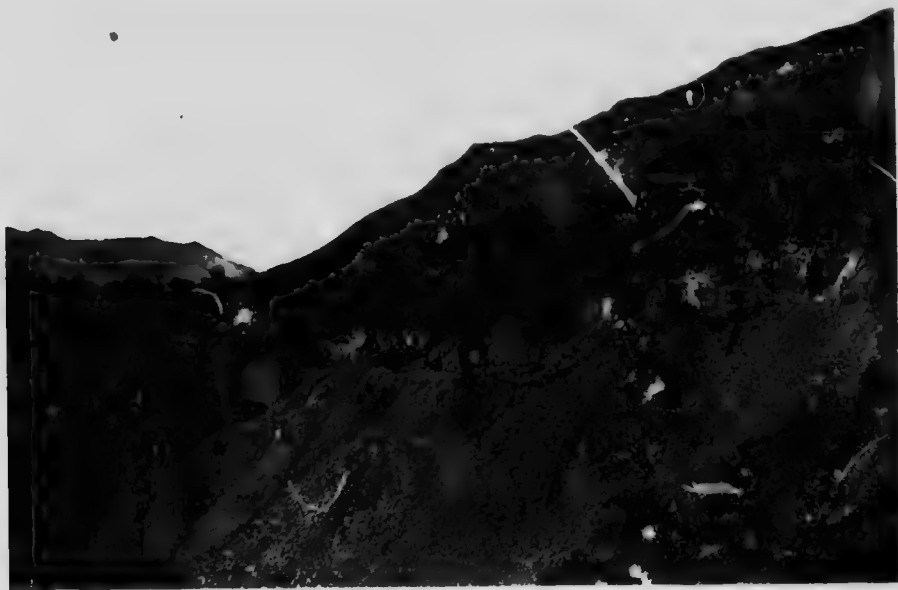
With the exception of the uncombined water, the analyses represent the composition of the ores after drying at 100° C. Leaner ores are mixed with richer to produce a material for shipping that contains about 6 per cent. of nickel. Garnierite varies greatly in composition, owing to mutual replacement of nickel and magnesium.

* Comprised in silica.

† From Report of Roy, Ont. Ni. Com., 1917, p. 248.

serious rival. This illustrates sufficiently the importance of the lateritic nickel deposits of the island colony.

During recent years, under normal conditions, the annual output of New Caledonia is between 5,000 and 6,000 tons of metallic nickel. In 1916 Sudbury produced 41,000 tons, an abnormally high output due to demands created by the war.



Nickel Mine at Dumbéa, New Caledonia.

Cobalt Ores

The lateritic cobalt ores of New Caledonia occur under the same conditions as do manganese ores of India, of similar origin, described by Fermor and others. While the cobalt ores are of indefinite composition, the name asbolite is usually applied to them. The metals cobalt and manganese are carried downward in solution and, in certain cases, through some little understood cause, finally segregate into nodules and irregular veins or veinlets in the mass of the laterite. In so far as the author observed, deposits of laterite that are worked for nickel in New Caledonia have not been worked for cobalt, although deposits of both metals in some places occur close together, as at Poro on the east coast of the island. Cobalt is becoming of increasing importance as a constituent of alloy steels, and probably the deposits of the metal in New Caledonia will again become of economic value, especially as those of Cobalt, Ontario, are of decreasing importance.

The following analyses of New Caledonia cobalt ores are taken from E. Glasser's report.¹ They show the variable composition of the ores.

¹ Richesses Minérales de la Nouvelle-Calédonie, Paris, 1904.

TABLE No. 3
Analyses of New Caledonia Cobalt Ores

	1	2	3	4	5	6
SiO ₂	50.75	32.00	34.00	16.40	2.20	23.09
Fe ₂ O ₃	11.50	20.00	11.43	15.50	8.91	16.06
Mn ₂ O ₃	14.00	26.50	19.05	12.07	23.62	17.59
Al ₂ O ₃				14.60	14.29	10.30
MgO and CaO	14.50	3.06			2.38	2.23
CoO	2.50	3.50	3.80	3.00	7.76	5.56
NiO			1.04	1.48	1.64	1.48
Water, etc., loss on ignition	6.80	15.50	30.68	36.95	29.20	23.69

Iron Ores

While lateritic iron ores have been smelted in small primitive furnaces in India and elsewhere for a long period, it was only with the discovery of the true character of the Cuban deposits and their development that ores of this class came to receive due attention. In three or four areas in Cuba that have been carefully examined there are estimated to be a total of at least 3,000,000,000 tons of merchantable ore which can be mined by steam shovel methods. In the present workings the ores are mined to an average depth of about 19 feet. In addition to their mode of occurrence and origin, these ores are of interest owing to their containing two metals, nickel and chromium, of great importance in alloy steels. The composition of the ores is shown in table No. 4. Shipments of these ores to the United States began early in 1910. The nodulized or dehydrated ore averages: Fe 55-56 per cent., Ni 1-1.2, Cr about 1-2, SiO₂ 4-4.4, Al₂O₃ 11-11.5, absorbed water 3-3.5.

More recently large deposits of ores of similar character and origin have been discovered in Borneo, island of Seboekoe, where the quantity is estimated to be at least 300,000,000 tons. One of the Philippine Islands, Mindanao, has deposits of even greater size, 400,000,000 tons or more, the character of which was not recognized till 1914.¹

While lateritic iron ores have now been proved to be of great economic importance, it is interesting to note that scarcely more than a decade ago those of a country as accessible as Cuba lay with their importance unrecognized. The character of the small nodules of ore that are found at the surface of the deposits was known, but the "red earth" with which they were associated was thought to be clay. Almost by accident the "clay" was discovered to be valuable iron ore.

Lateritic iron ores of the character of those of Cuba are to be looked for in every tropical country where basic rocks have been subjected to prolonged weathering. These ores are destined to play a very important part in the iron industry.

The percentage of combined silica in the Cuban deposits, whether they are of the nature of laterites, as defined by Fermor, or whether they are of the nature of ochre, ferruginous clay, was for a time of great legal importance. The title to the lands, which had been applied for or denounced as iron ore deposits, depended on whether the ores were true iron ores or whether they were ochres

¹ See Report Royal Ont. Ni. Commission for summary of the literature on iron ores of the three countries mentioned.

(limonite and clay).¹ Evidence that the deposits contained little combined silica, clay, confirmed the titles of those who had denounced the deposits as iron ores against those who had denounced them as ochres.

The following table shows the character of the ore at various depths, in the Mayari area:

TABLE No. 4
Chemical Analyses Showing Alteration of Serpentine Rock to Iron Ore in the Mayari District, Cuba.²

Analyses supplied by Spanish-American Iron Co

Depth, Feet	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	Fe	MgO	Cr	Ni+Co	P	S	H ₂ O+	Total
0-1	2.58	15.71	66.20	46.37	.....	0.92	0.38	0.016	0.12	10.20	96.126
1-2	2.38	20.81	64.70	45.34	.....	0.96	0.33	0.022	0.12	10.63	99.952
2-3	1.60	17.43	68.40	47.81	.....	0.96	0.42	0.018	0.14	9.15	98.118
3-4	1.42	14.23	68.70	48.09	.....	1.04	0.76	0.019	0.16	9.50	95.429
4-5	1.56	8.47	70.60	49.46	.....	1.27	0.61	0.016	0.17	10.14	92.836
5-6	2.90	10.24	72.35	50.56	.....	1.66	0.84	0.016	0.20	10.96	99.166
6-7	2.20	8.29	72.90	51.00	.....	2.19	1.09	0.007	0.19	11.35	98.217
7-8	2.58	4.92	71.85	50.28	.....	2.19	1.15	0.006	0.14	11.57	94.506
8-9	3.00	7.25	71.55	50.15	.....	2.59	1.14	0.006	0.16	12.12	97.916
9-10	2.44	6.91	72.40	50.63	.....	2.08	1.21	0.005	0.16	12.35	97.555
10-11	2.42	6.31	71.40	49.94	.....	2.00	1.36	0.005	0.14	12.40	96.035
11-12	2.72	7.05	70.55	49.46	.....	2.08	1.31	0.004	0.15	12.40	96.264
12-13	2.56	6.77	70.20	40.08	.....	1.62	1.37	0.004	0.10	13.50	96.124
13-14	2.52	6.23	70.55	49.46	.....	1.85	1.41	0.005	0.14	13.12	95.825
14-15	2.76	6.58	71.85	50.22	.....	1.89	1.38	0.007	0.21	12.45	97.127
15-16	2.78	6.53	70.00	48.98	.....	2.16	1.33	0.007	0.19	12.35	95.347
16-17	2.98	6.43	69.80	48.84	.....	2.19	1.42	0.007	0.19	12.57	95.587
17-18	3.20	5.53	70.45	49.32	.....	2.00	1.35	0.007	0.15	2.90	95.587
18-19	3.66	6.51	69.20	48.42	.....	2.43	1.34	0.005	0.06	2.73	95.935
19-20	6.84	8.49	63.35	44.32	.....	2.51	1.36	0.004	0.08	12.80	95.434
20-21	7.44	5.13	66.55	46.58	.....	2.27	1.57	0.003	0.09	12.45	95.503
21-22	8.46	4.99	57.80	40.47	0.00	2.16	1.47	0.006	0.08	12.71	87.676
22-23	11.04	8.38	60.00	43.49	0.00	1.85	1.74	0.002	0.09	14.07	99.272
23-24	15.86	4.70	63.90	44.62	0.00	2.19	1.57	0.003	0.09	11.73	100.043
24-25	17.40	4.00	62.90	40.00	0.50	1.85	1.43	0.003	0.12	11.64	99.843
25-26	22.54	4.57	50.25	35.12	6.49	1.89	1.80	0.002	0.06	13.65	101.252
26-27	28.60	4.18	32.85	23.00	18.23	1.12	1.43	0.003	0.09	13.45	99.953
27-28	35.64	2.33	18.25	12.78	27.55	0.77	1.35	0.001	0.06	14.23	99.981
28-29	39.80	1.39	10.14	7.10	33.69	0.20	0.97	0.001	0.06	13.31	99.561

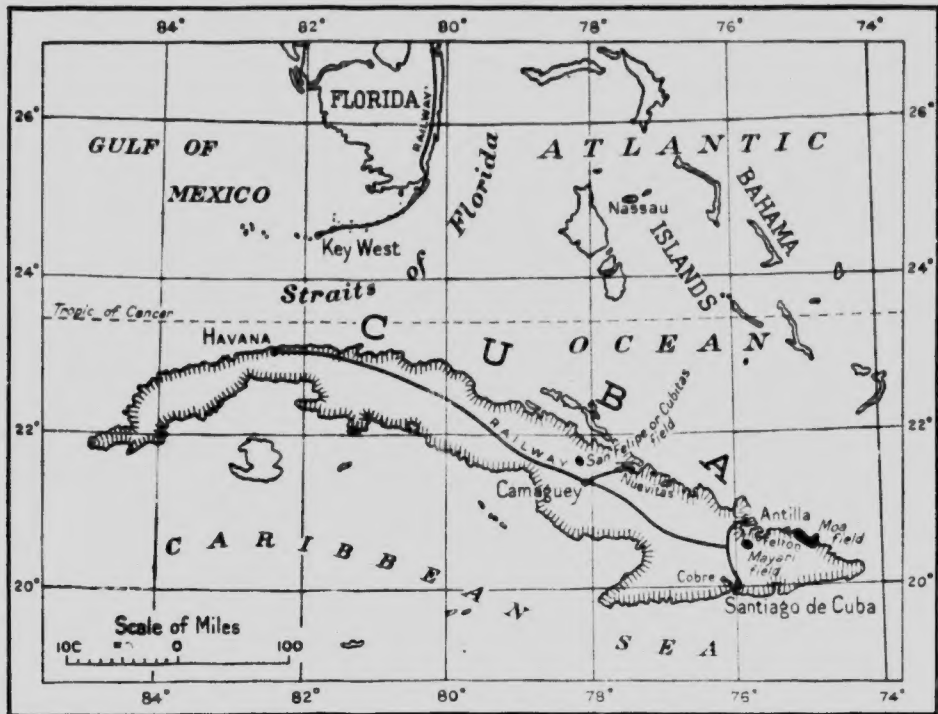
Manganese Ores

Lateritic manganese ores of India, although of much less importance than ores of the metal of other origin, are of much interest. Their mode of occurrence is similar to that of the cobalt ores of New Caledonia.

Fermor says: manganese, when present in laterite, usually renders itself conspicuous by segregating into forms, as a rule black nodules or veins of psilomelane or pyrolusite, that one would without any hesitation call manganese-ore. It rarely seems, except in very small quantity (or in proper manganese-ores), to become blended with the other constituents of laterite, so as to form intimate mixtures similar to those that the oxides of iron, aluminum, and titanium, so commonly form with one another. Indeed, many large masses of laterite can be found that seem to be completely free from manganese. As it cannot be supposed that the rocks from which the iron and alumina of the laterite were derived contained no manganese, it is necessary to suppose that with solutions containing manganese, iron, and aluminum, a selective precipitation can take place in nature.³

¹ The Mayari and Moa Iron-Ore Deposits of Cuba, A.I.M.E., Vol. XLII, pp. 109-115.
² Characteristics and Origin of the Brown Iron-Ores of Camaguey and Moa, Cuba, Ibid., pp. 116-137.

³ Additional data on origin of Lateritic Iron Ores of Eastern Cuba, C. K. Leith and W. J. Mead, A.I.M.E., Vol. LIII, 1915, p. 76.
Memoir, Geol. Surv. India, Vol. XXXVII, p. 381.



Map of Cuba.

The following table of analyses is taken from Fermor's report.²

TABLE No. 5
Analyses of Lateritic Manganese Ores

	Belgaum	SHIMOGA		Sandur
		Higher grade ores	Lower grade ores	
Manganese	31.2 -60.8	44-56	30-38	39.47-54.39
Iron	0.1 -18.4	2-10	10-20	5.38-19.40
Silica	0.6 - 2.5	1- 3	2- 6	0.43- 1.00
Phosphorus	0.01- 0.12	0.015-0.600	0.01- 0.6	0.016-0.033

² Ibid., p. 389.

The situation as regards manganese, especially in the United States, is now serious, and is likely to continue so long as the war lasts. By far the most important producers of manganese ores are Southern Russia, British India and Brazil. As is the case of nickel, a very few countries supply the greater part of the world's requirements for manganese.

Aluminum Ores

That in India extensive deposits of bauxite, the chief ore of aluminum, are of lateritic origin is seen from the following:

Some years ago it was discovered that many of the lateritic deposits of India are highly aluminous, such aluminous varieties being identical with the substance known as bauxite. Field-work carried out since 1903 by the officers of the Geological Survey has revealed the existence of extensive deposits of this mineral substance in various parts of India, and chemical investigation in the Geological Survey Laboratory and at the Imperial Institute has shown that certain of the Indian bauxites compare very favourably with the Irish, French, and American bauxites placed on the English market. . . . Eight analyses of specimens and samples of the Balaghat bauxites have given results ranging between the following limits:—

Al ₂ O ₃	51.62 to 58.83
Fe ₂ O ₃	2.70 to 10.58
TiO ₂	6.22 to 13.76
SiO ₂	0.05 to 2.65
Combined water ..	22.76 to 30.72
Moisture	0.40 to 1.14

Corresponding to 71.2 to 80.8 per cent. of Al₂O₃ after calcination. With these may be compared the following figures showing the range of analysis of some Irish, French, and American bauxites of commerce analysed at the Imperial Institute:—

Al ₂ O ₃	42 to 63
Fe ₂ O ₃	2 to 21
TiO ₂	2 to 6
SiO ₂	3 to 13
H ₂ O	12 to 28
Moisture	5 to 16

Two Katni bauxites gave the following analyses:—

	No. 1	No. 2
Al ₂ O ₃	64.48	52.67
Fe ₂ O ₃	3.7	7.04
TiO ₂	11.61	7.51
SiO ₂	0.38	1.26
H ₂ O	19.38	29.83

From these figures it will be seen that the Balaghat and Jabulpore bauxites are of very high grade. There seems also to be little doubt that large quantities of the mineral are available, and the commercial feasibility of making use of these deposits has consequently been under investigation for some years.¹

While not dealing specifically with the character or origin of laterites, W. J. Mead² in his paper on the "Occurrence and Origin of the Bauxite Deposits of Arkansas," furnishes data that make the attempt to define and classify laterites still more difficult. It will be seen from the following notes from Mead's paper that the bauxite is a product of weathering of nepheline syenite. Moreover, the analyses show that the upper layers of the deposits, formed in situ, are to be

¹ Records Geol. Surv. of India, Vol. XLVI, 1915, pp. 228, 229.

² Ec. Geology, 1915, pp. 28-54.

classified as clays, while lower layers, with their high content of bauxite and low percentage of silica, according to the definitions proposed by most writers, are to be classed as laterites. These bauxite-holding deposits, therefore, considered as a whole, cannot be classed as either laterite or clay.

Mead says: It appears that normal weathering of the syenite to kaolin and allied minerals has simply continued one step further in breaking down these hydrous aluminum silicates to hydrous aluminum oxide.

Downward Secondary Enrichment of Alumina

The top portion of the bauxite deposits is characteristically higher in silica than the bauxite below. In many instances it has been necessary to remove the upper eighteen inches or two feet of high silica ore before mining, thus adding greatly to the mining cost. A typical instance is shown in the following table of analyses of a series of samples from a test pit in bauxite.

TABLE No. 6

Marked.	SiO ₂	Fe ₂ O ₃	TiO ₂	Loss on ignition.	Al ₂ O ₃ by Diff.
3' - 5'	24.85	4.84	1.3	22.97	46.04
5' - 8'	13.54	3.14	1.5	27.52	54.30
7' - 9'	14.63	3.24	1.5	28.22	52.41
9' - 11'	7.73	2.63	1.3	30.36	57.98
11' - 13'	9.96	3.19	1.4	29.04	56.41
13' - 15'	9.65	1.59	1.7	29.89	57.16
15' - 17'	9.00	2.99	1.6	29.56	56.76
17' - 19'	13.29	2.32	1.8	27.69	54.90
19' - 21'	11.88	2.11	1.8	28.44	55.77
21' - 23'	7.08	2.57	2.0	30.25	58.09
23' - 25'	6.84	2.02	1.7	29.91	59.53
25' - 27'	7.33	3.04	1.7	30.63	57.30
27' - 29'	5.52	2.16	2.8	30.69	58.83
29' - 31'	5.70	2.11	1.9	30.53	59.76

This increase in silica toward the surface may be due to an actual downward secondary concentration of alumina. Those portions of kaolin and halloysite which persist after the main portion of the kaolinized syenite has been altered to bauxite are the dense impervious parts. Bauxite is soluble in surface solution to a certain extent, and on being dissolved and carried downward leaves the kaolin and hence the silica, in relatively higher percentage at the surface. The alumina carried down is deposited below, assisting in the formation of the pisolites.

Various writers on the geology of India have shown the wide distribution of bauxite in that country and have emphasized the fact that bauxite is a variety of laterite. That the deposits of Arkansas are of great importance is shown by the fact that over 80 per cent. of the large production of bauxite in the United States, during the five years up to 1915, came from that State.

Gold Ores

Among the most interesting descriptions of lateritic gold deposits are those of British Guiana by J. B. Harrison.¹ The following quotations from this author show the character of the deposits.

¹ The Geology of the Goldfields of British Guiana, 1908.

The diabase intrusions occur in belts, generally stretching across the colony in a north-westerly and south-easterly direction. The intrusions vary from narrow dykes, only exposed in the courses of the rivers during very dry seasons, some being not more than from two to three feet across, to low hills and to mountain ranges, some of which—for example, the Eagle mountains in the Potaro gold district—exceed in height two thousand feet. The tops and sides of the hills and mountains, except where they have suffered great denudation, are covered with ironstone gravel, while the lower parts of the districts in which diabase forms the country are covered up with strata of laterite, frequently over one hundred feet in depth, and in places interspersed with nests of secondary quartz, or traversed by veins and stringers of quartz, or, less often, by lenticular layers of secondary quartz, closely resembling, when cut through by mining shafts, tunnels and trenches, true quartz-reefs. The quartz rock in all these forms is not unfrequently auriferous, the metal being dispersed through it in a very irregular manner, especially in the larger lenticular layers, which in many parts are nearly, or even entirely, barren of gold, and in others are "bonanzas" carrying at rates from twenty to, in places, several hundreds of ounces of the precious metal to the ton of the rock. Unfortunately hitherto these bonanzas have proved few and far between; but there is no reason for assuming that they will not be found in many places in the enormous area of the laterite deposits which up to the present has not been prospected, as they have been in similar places at intervals in the past. Gold also occurs as paint gold, as gold dust, and as nuggets of varying sizes in the laterite.¹

No quartz veins occur in the diabase, whilst in the unaltered epidiorite and hornblende-schist only, as a rule, narrow veins and stringers of quartz are found. But veins and lenticular masses of quartz which are, not unfrequently, rich in gold are of common occurrence in the decomposition-products of the epidiorite, hornblende-schist and diabase.²

Where the country rock traversed by these veins has decomposed to a great depth their size has been largely increased, having been added to by silica dissolved from the decomposing rocks by percolating waters. At the same time as silica was thus deposited a concentration and deposition of the gold contained in the decomposing rocks took place, and thus the quartz veins became enriched in this metal in proportions varying with those present in the country rock, with the result that the veins found in decomposed epidiorite and hornblende-schist are, as a rule, richer in gold than are those found in decomposed acidic rocks.³

The veins of quartz which traverse the dark-red decomposition-products of the basic rocks are frequently very rich in gold and near their outcrops, these parts being far more auriferous than are the remaining portions of the veins. Similarly the talcose selvages of these veins are often highly auriferous.⁴

¹ Ibid., pp. 22, 23.

² Ibid., p. 186.

³ Ibid., pp. 186, 187.

⁴ Ibid., p. 187.